



**SLAMS EARLY CAREER FORUM 2018**

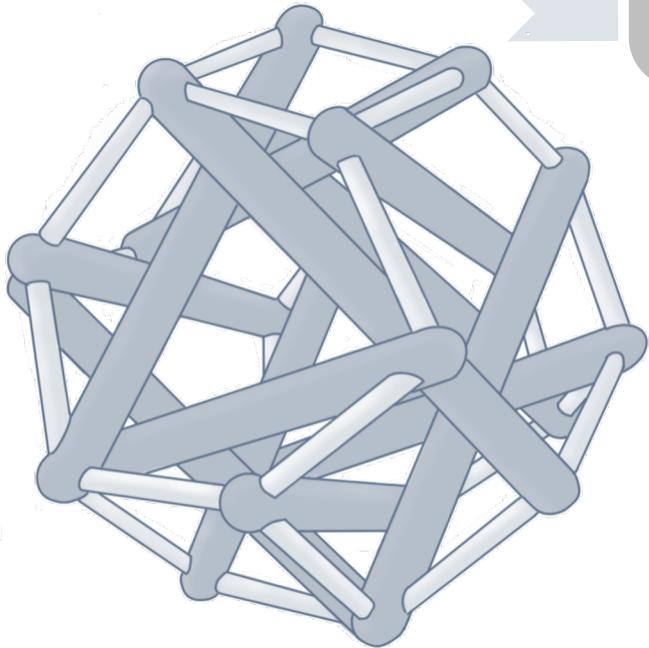
# **Tensegrity Ultra-Lightweight Probe**

Christine Gebara  
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Technology

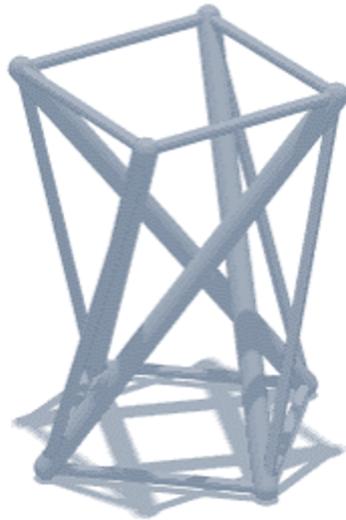


**Jet Propulsion Laboratory**  
California Institute of Technology

What is a tensegrity structure?



Why are they interesting



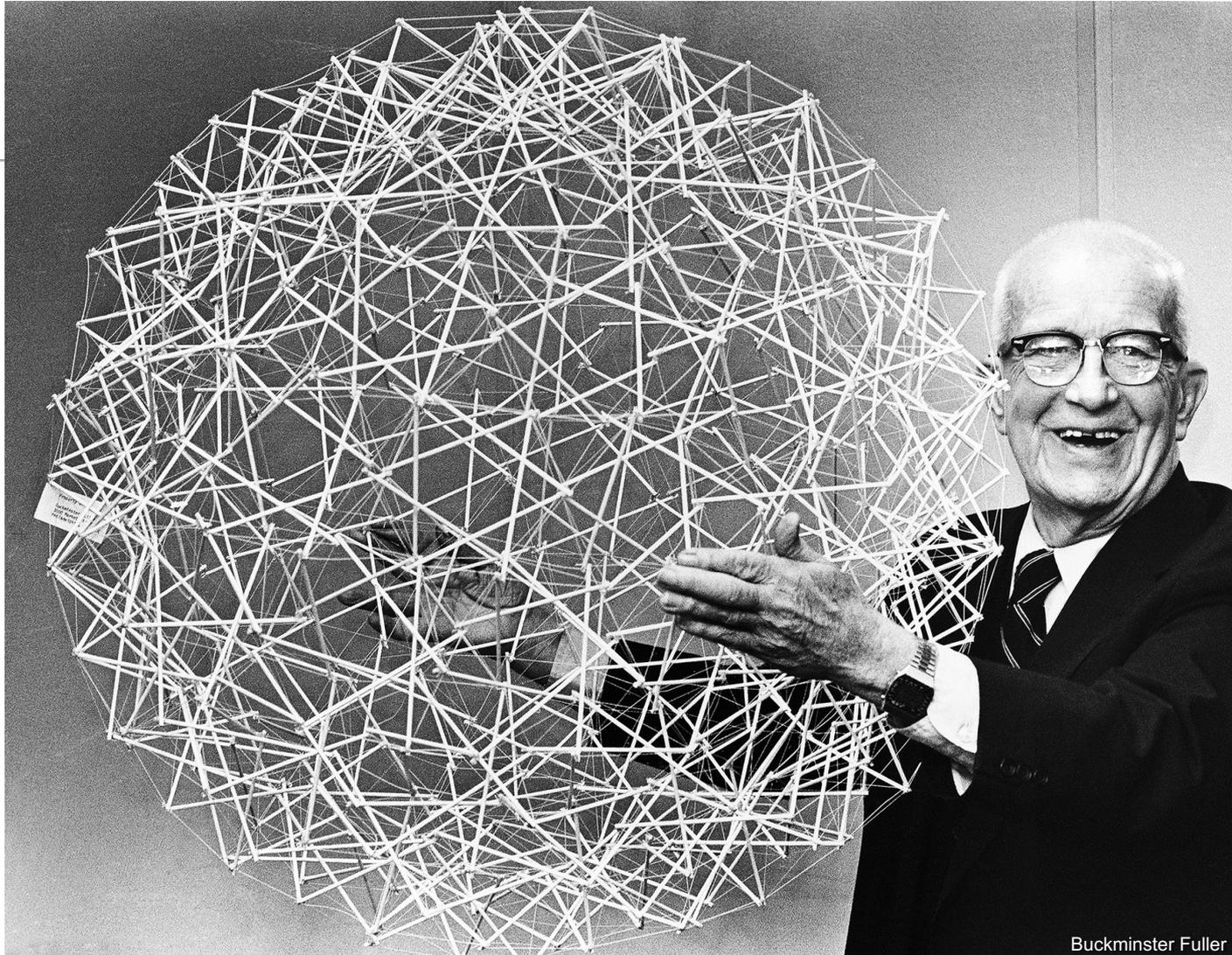
Work being done at JPL

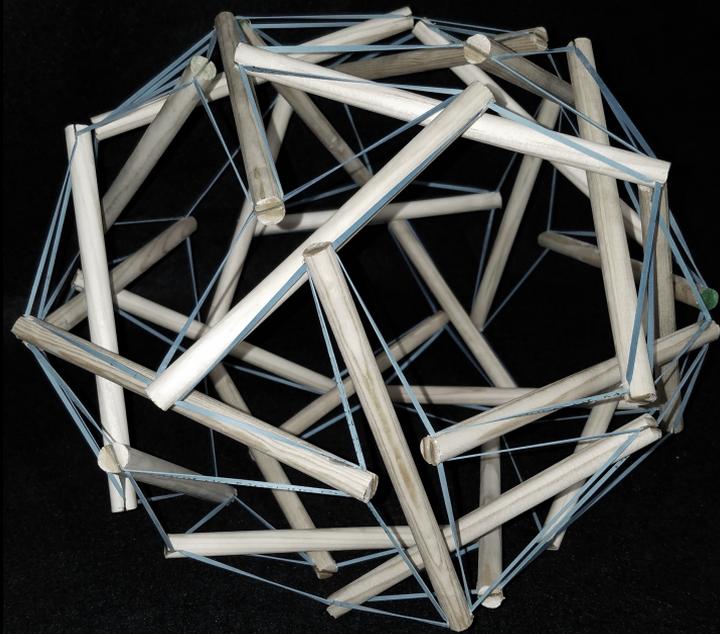
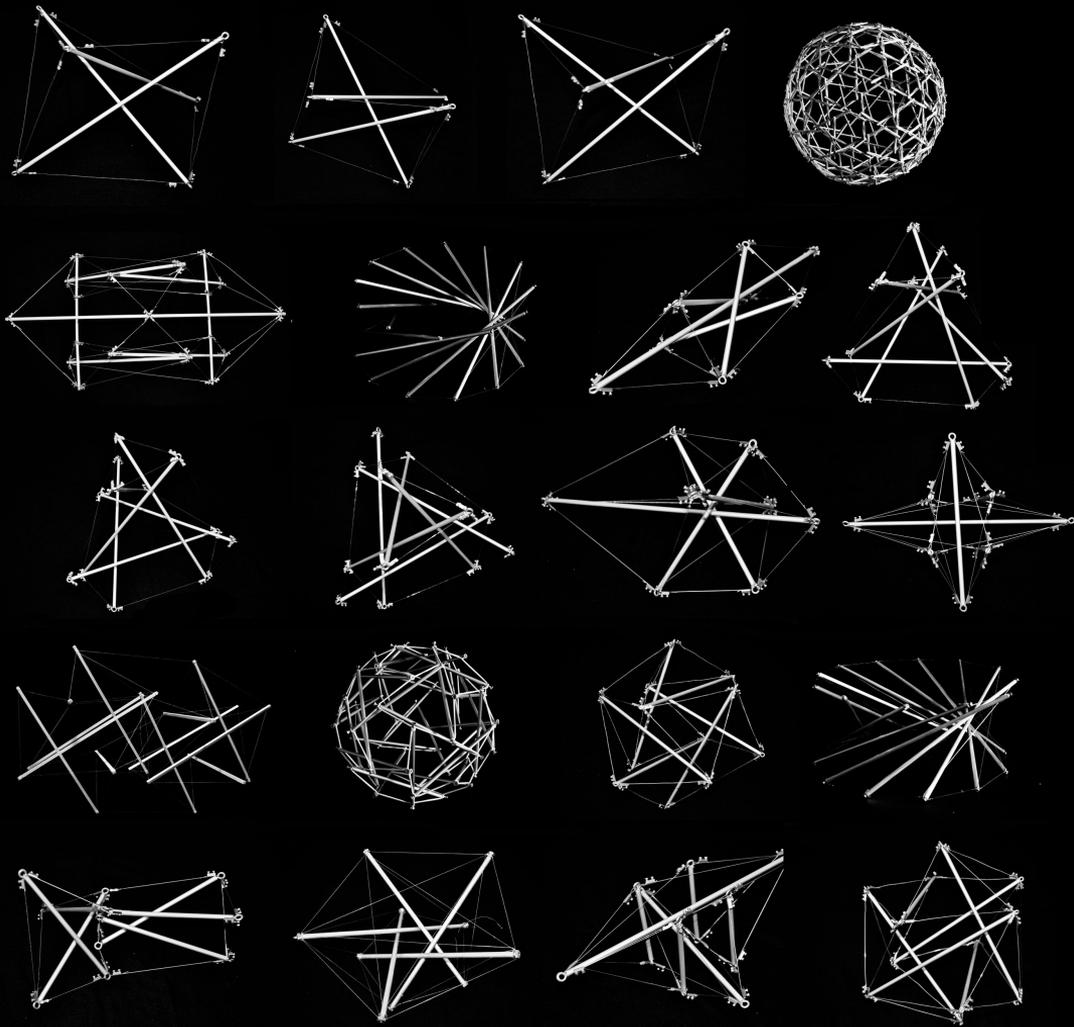
# Tensegrity

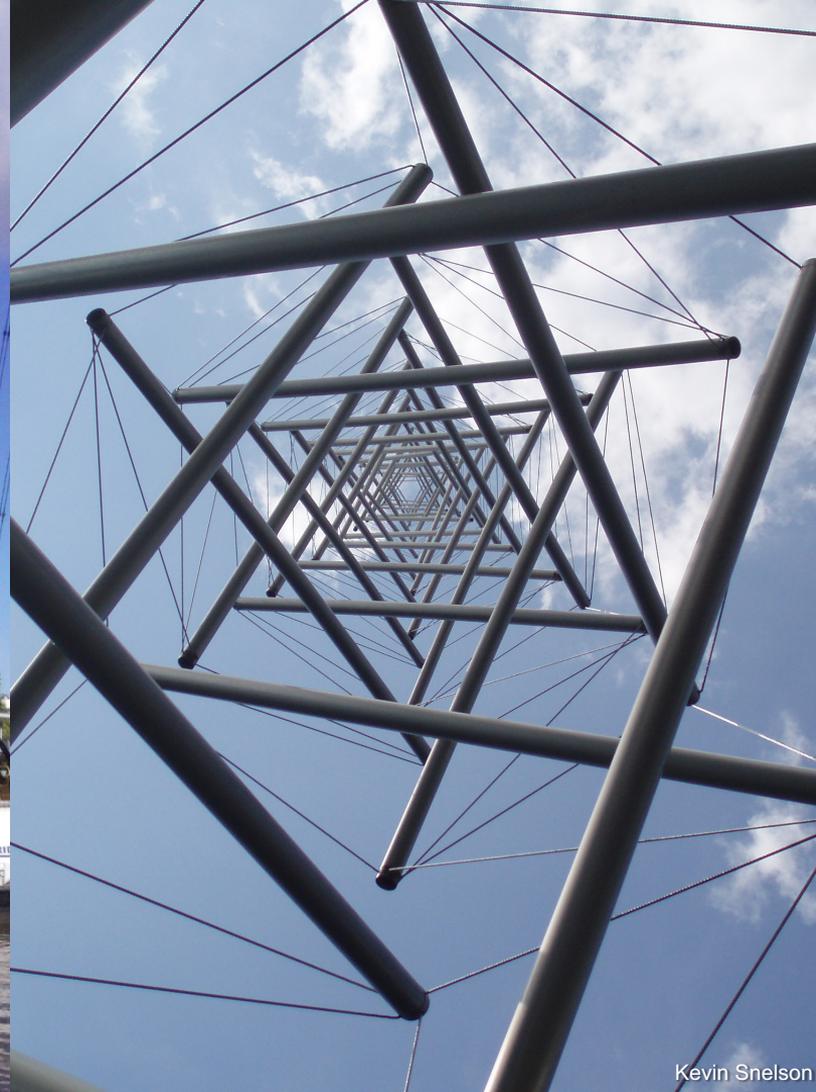
Compression members suspended within a network of tension members.

Biomimetic structural inspiration.

Applications scale from sculpture, architecture, and engineering.







# Tensegrity Characteristics

## Descent & Landing

Impact tolerant

High drag

Some lift

Numerous impacts

Light-Weight

Robust To Failures

Distributed loading

Omnidirectional

Tunable

Field of View

Energy-Efficient

Swimming

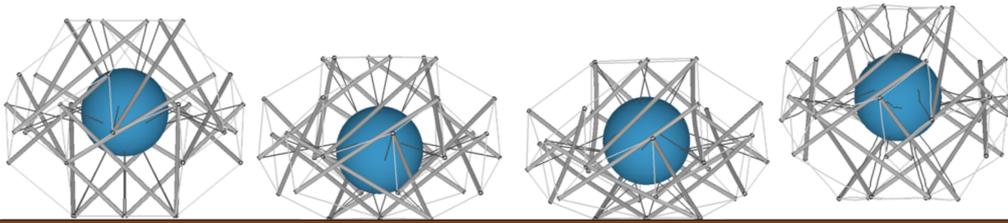
Roving

## Mobility

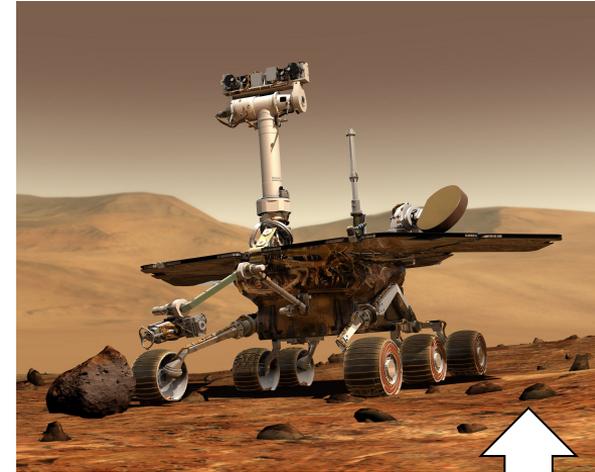
# Basis

Where does tensegrity fit in?

- Opportunity rover airbags
- Opportunistic exploration
- Swarms
- Small to mid-sized landing scenarios
- Multiple Impacts

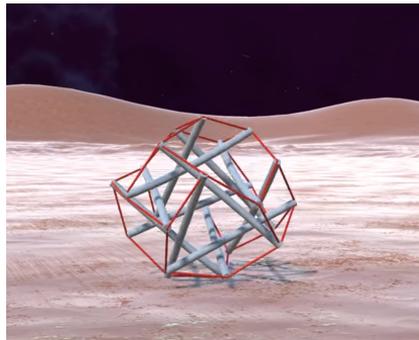
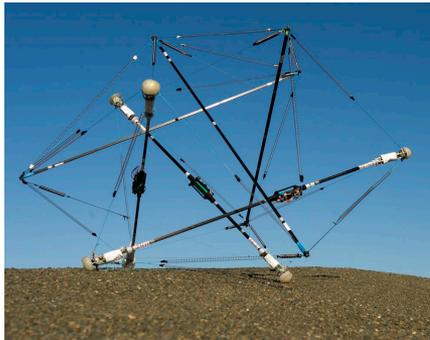


Bayandor – NIAC 2016



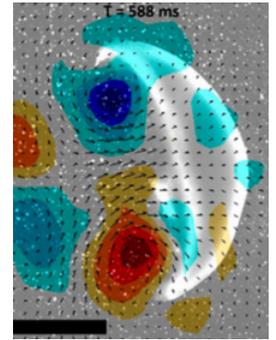
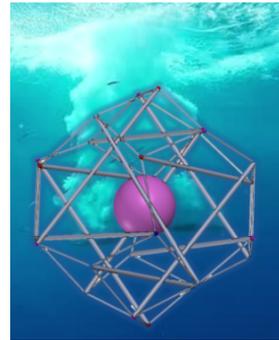
## Icy/Rocky Worlds

- End-to-End exploration solution
- Impact resistant
- Robust locomotion architectures
- Low terminal velocity
- High payload mass fraction
- Can sustain numerous impacts



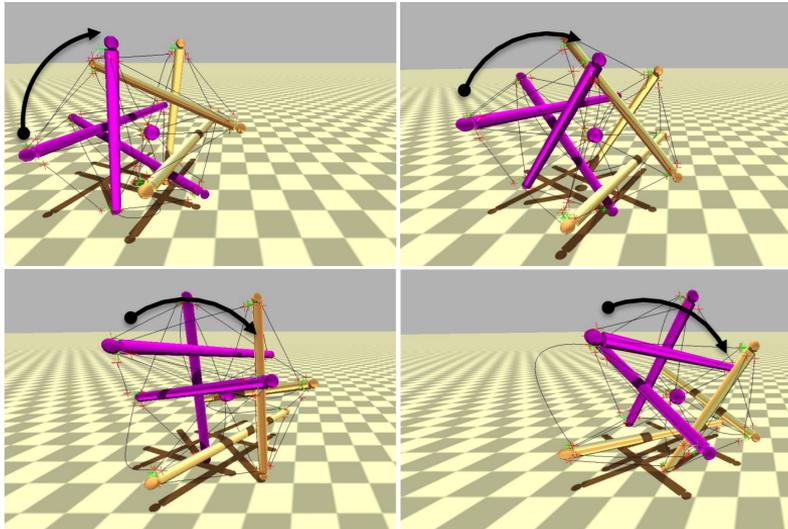
## Ocean Worlds

- End-to-End exploration solution
- Payload is protected without the obstruction of a full enclosure, allowing for constant data collection
- Efficient locomotion underwater
- Low terminal velocity



## Rolling Locomotion

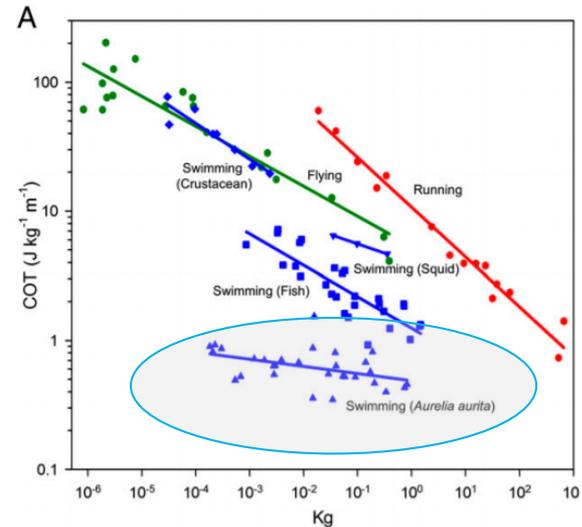
- Redundant to cable loss
- Capable of rolling uphill
- Studied in NIAC at Ames
- Numerous methods (CG, lengths, ect.)



SuperBall, SunSpiral, NASA-ARC

## Swimming Locomotion

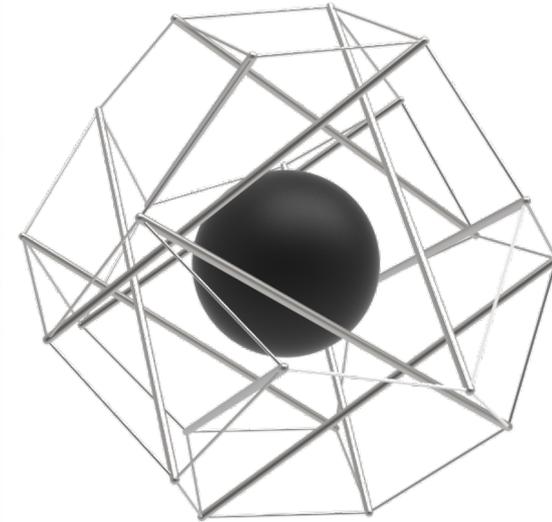
- Jelly fish locomotion is most efficient form of locomotion up to a weight limit
- Reynolds number difference from descent to swimming



# Descent and Landing in our Solar System

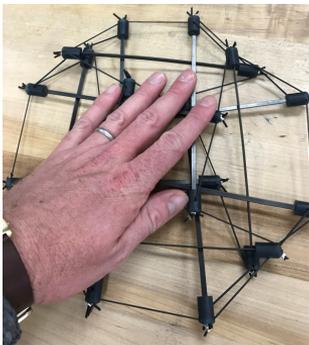
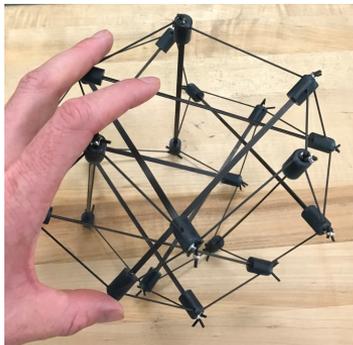
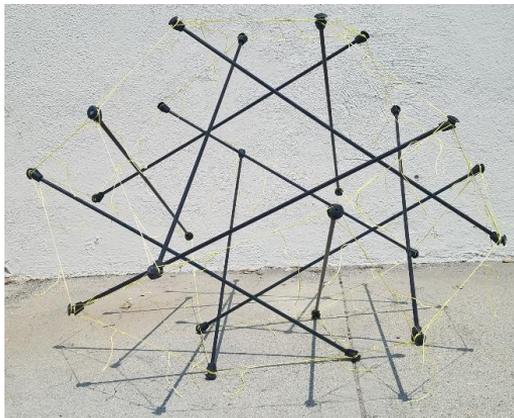
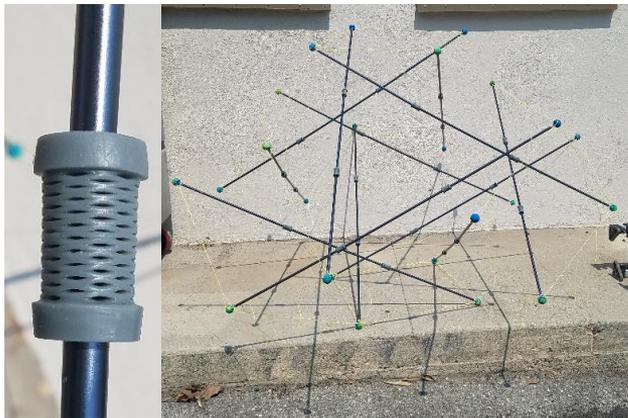
Measure	Units	Earth	Titan	Europa	Miranda	Mars	Moon	Ceres
Reynolds Number	n/a	.5 ->1 E6	2E5	n/a	n/a	2.5E-5 (est. avg)	n/a	n/a
Drop Height	m	11,000	40,000	10,000	10,000	7000	10,000	10,000
Impact Speed	m/s	129.76	3.65	162.172	39.7492	8.8E3	180	73.48
Gravity	m/s^2	9.81	1.352	1.315	0.079	3.711	1.62	.27
Cd	n/a	.4	.45	-	-	1.6	-	-
CI	n/a	0 (no spin) .15 (spin)	0 (no spin) .1 (spin)	-	-	0 (no spin) .01 (spin)	-	-

1m class 20kg probe.

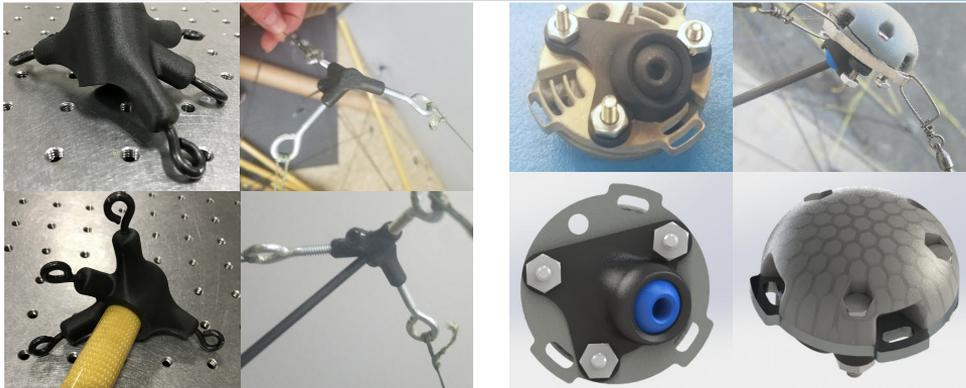


With help from Anna Woodmansee, JPL

# Prototyping



# Joint Design

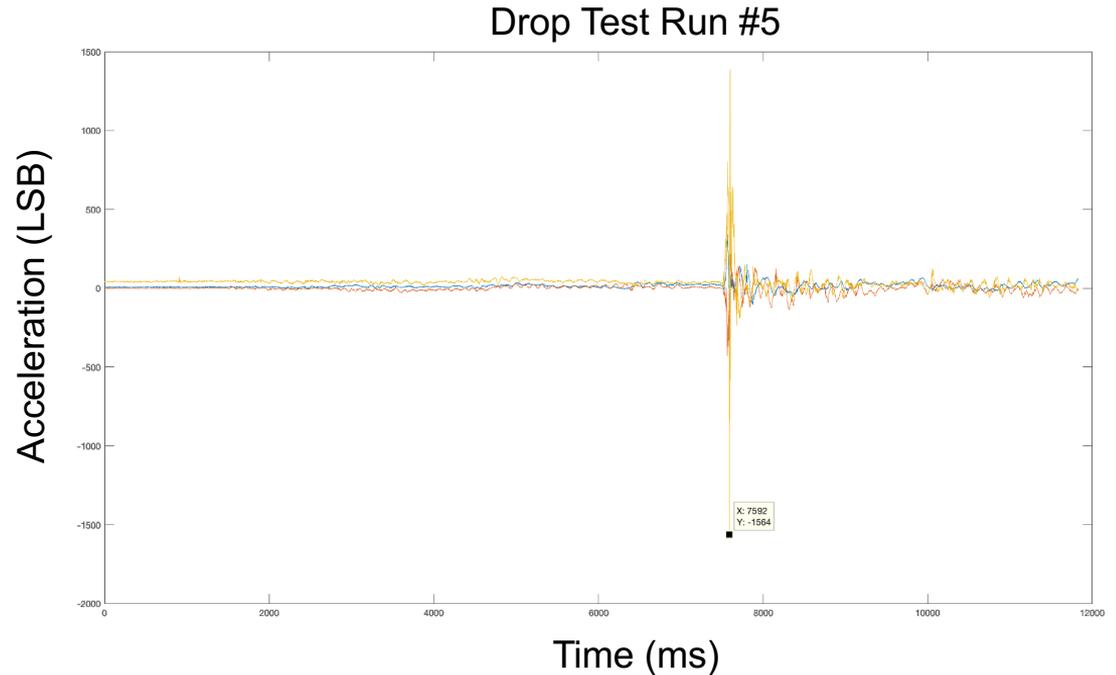


Some images and design by Julie Kraus, Georgia Tech/JPL



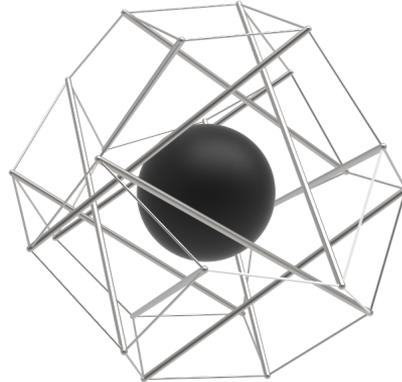
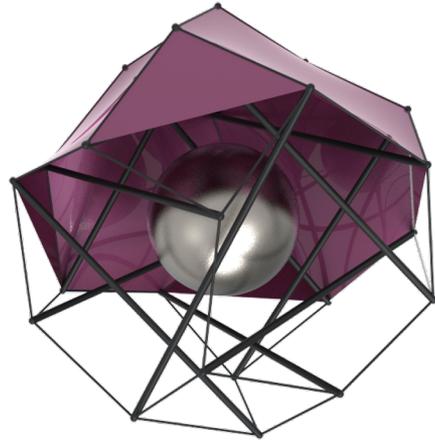
# Test data

- Initial testing with a brittle Kevlar tensegrity
- Peak of 75 g's on impact
- Confirmation that elasticity and buckling of compression members is very important to lowering impact loads
- Payload environments need to be fully defined



# Summary and Next Steps

- JPL has developed effective methods for tensegrity manufacturing
- Ongoing testing will empirically prove mass payload fraction
- Tensegrity structures parametric testing
- Swimming prototype
- Payload prototype with Cal Poly



# The Tensegrity Team

- Kalind Carpenter (JPL)
- Julie Kraus (JPL/Georgia Tech)
- Dr. Samuel Case Bradford (JPL)
- Dr. Julian Rimoli (Georgia Tech)
- Dr. Doug Hoffman (JPL)
- Anna Woodmansee (JPL)
- Collaborators at Ames Research Center

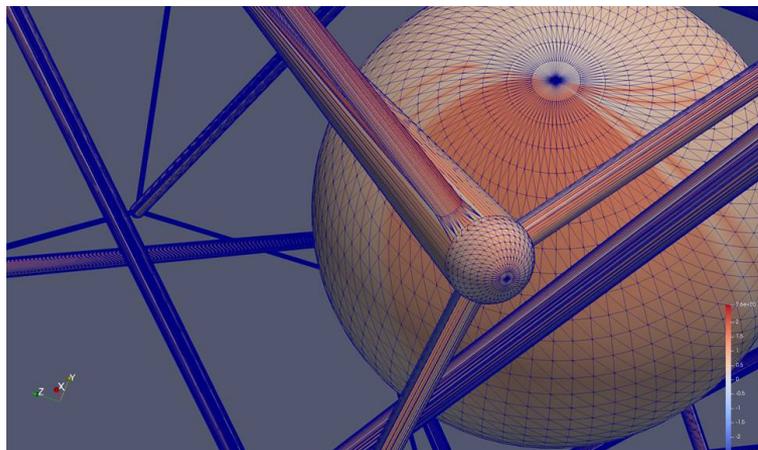
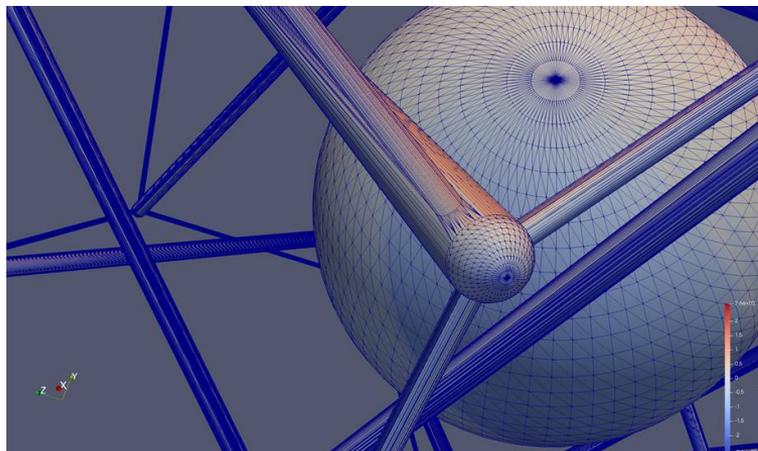
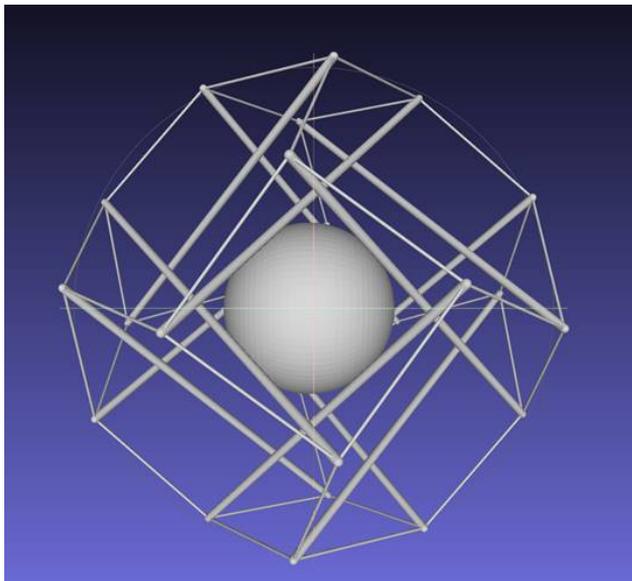


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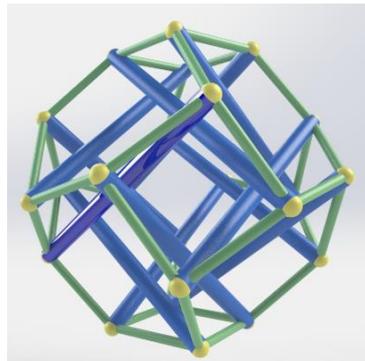
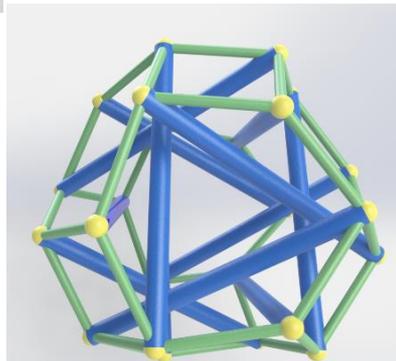
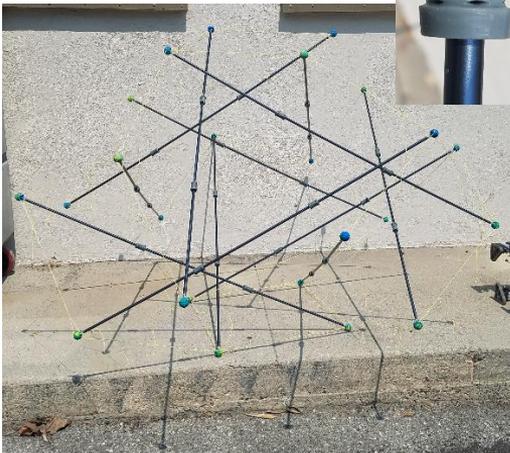
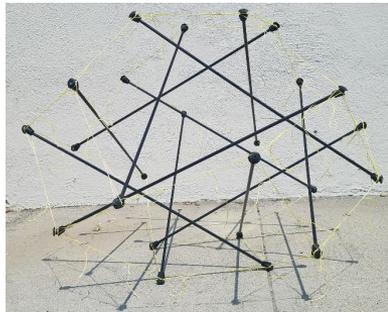
# Sources

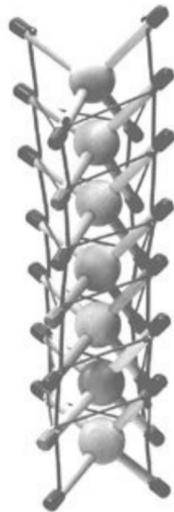
Slide	Sources
2	<ul style="list-style-type: none"> <li>• <a href="https://en.wikipedia.org/wiki/Tensegrity#/media/File:Tensegrity_simple_3_RL.png">https://en.wikipedia.org/wiki/Tensegrity#/media/File:Tensegrity_simple_3_RL.png</a></li> </ul>
3	<ul style="list-style-type: none"> <li>• <a href="https://www-tc.pbs.org/wnet/americanmasters/files/2001/12/BuckminsterFuller.jpg">https://www-tc.pbs.org/wnet/americanmasters/files/2001/12/BuckminsterFuller.jpg</a></li> <li>• <a href="https://i.pinimg.com/564x/5b/f5/3b/5bf53b5549bb83deae5ff0247265bb1d.jpg">https://i.pinimg.com/564x/5b/f5/3b/5bf53b5549bb83deae5ff0247265bb1d.jpg</a></li> </ul>
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5	<ul style="list-style-type: none"> <li>• <a href="https://www.fenner-esler.com/blog/tensegrity-structures-stabilization-through-tension/">https://www.fenner-esler.com/blog/tensegrity-structures-stabilization-through-tension/</a></li> <li>• <a href="https://upload.wikimedia.org/wikipedia/commons/5/5d/Kenneth_Snelson_Needle_Tower.JPG">https://upload.wikimedia.org/wikipedia/commons/5/5d/Kenneth_Snelson_Needle_Tower.JPG</a></li> </ul>
6	<ul style="list-style-type: none"> <li>• <a href="https://www.reddit.com/r/space/comments/4bt9j1/testing_the_mars_pathfinder_airbags_used_to_land/">https://www.reddit.com/r/space/comments/4bt9j1/testing_the_mars_pathfinder_airbags_used_to_land/</a></li> <li>• <a href="https://www.jpl.nasa.gov/missions/web/mer.jpg">https://www.jpl.nasa.gov/missions/web/mer.jpg</a></li> </ul>
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10	<ul style="list-style-type: none"> <li>• Contributions from Anna Woodmansee, JPL</li> </ul>
11	<ul style="list-style-type: none"> <li>• Contributions from Julie Kraus and Kalind Carpenter, JPL</li> </ul>
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13	<ul style="list-style-type: none"> <li>• Contributions from Case Bradford, Kalind Carpenter, and Christopher Lawler</li> </ul>
14	<ul style="list-style-type: none"> <li>• N/A</li> </ul>
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# CFD Pictures



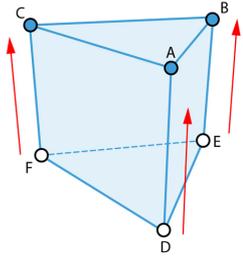
# Structure Pictures





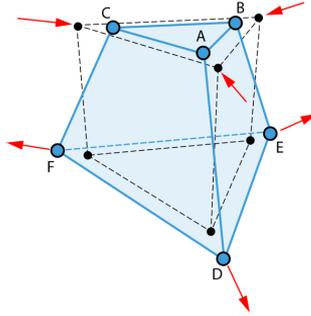
## Module variations

Extrude 90 - 110%



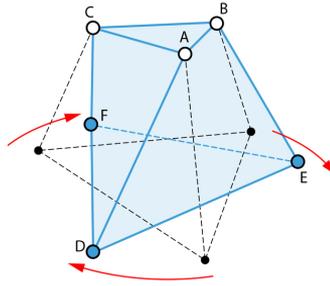
The height of the module informs the depth of the envelope.

Scale 10 - 20%



The scale of the top and base informs the degree of curvature.

Rotate 30° - 40°

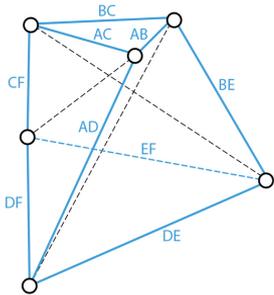


The rotation of the module is a result of tension in the tensegrity system.

[http://ad009cdnb.archdaily.net/wp-content/uploads/2014/10/542db8f4c07a80c9ea00042e\\_students-of-ball-state-construct-parametric-tensegrity-structure-for-local-art-fair\\_005\\_module\\_variation.jpg](http://ad009cdnb.archdaily.net/wp-content/uploads/2014/10/542db8f4c07a80c9ea00042e_students-of-ball-state-construct-parametric-tensegrity-structure-for-local-art-fair_005_module_variation.jpg)

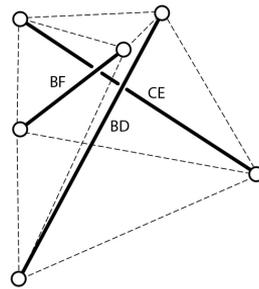
## Module components

Cables



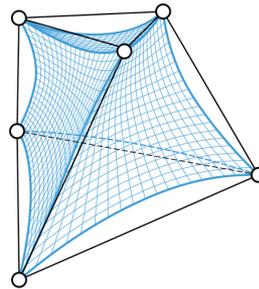
The two triangles with their connections form a closed network of continuous tension.

Struts



The aluminum struts inside this network of cables are in pure compression

Fabric



The fabric is added after the modules are assembled.